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Exposure of health care workers and occupants to coughed air in a hospital room with displacement air distribution: impact of ventilation rate and distance from coughing patient

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SUMMARY
The exposure of a doctor and a second patient to coughed air by an infected patient was studied in a simulated two-bed hospital patient room. The air temperature in the room, ventilated at two air change rates (3 h^{-1} and 6 h^{-1}) was kept 22 ^{o}C. Thermal manikin with realistic body shape and surface temperature distribution was used as the doctor standing 0.55, 1.1 or 2.8 m downstream the cough. A coughing thermal dummy, lying in one bed and a second thermal manikin in the other bed (1.3 m away), were used as the “sick” and the “exposed” patients. The cough consisted of 100% CO_2. The doctor and the coughing patient faced each other. The Peak Cough Time (PCT) was around 6 s, when the doctor was 0.55 m downstream the cough and increased when the distance between the sick patient and the doctor increased. The highest Peak Concentration Level (PCL) for the doctor, i.e. excess of CO_2 level in inhaled air above background concentration (ppm), for the three measured distances was at 6 h^{-1}. PCL decreased with distance. The exposure of the second patient was low when the doctor was at 0.55 or 1.1 m downstream the cough (blocking effect), but was quite high when at 2.8 m. 6 h^{-1}, recommended in present hospital standards as minimum ventilation rate in hospital patient rooms, resulted in elevated exposure to coughed air for the doctor, suggesting increased risk from airborne cross-infection. Displacement air distribution does not reduce the risk from cross-infection.

KEYWORDS
Air distribution, hospital patient room, airborne cross infection, coughing thermal manikin, physical measurements

INTRODUCTION
Displacement ventilation has the benefit to provide higher air quality compared to mixing ventilation. Heat sources positioned close to the floor are important for the proper functioning of the displacement pattern, by entraining into rising convection flows the cool fresh air supplied with low impulse over the floor area. The low air velocities within the spaces ventilated by displacement air distribution does not allow effective evacuation of particles over 10µm and result in higher concentration of small particles in the lower region of the room (Lai and Cheng 2007, Mundt 2008). In hospital premise this will lead to deposition of particles on surfaces or they will stay in the lower part of the room. The particles may be captured by the convection flow around the human body, transported to the breathing zone and inhaled or ingested. If the particle nuclei are laden with pathogens they can infect the person and initiate a disease spread. Another disadvantage for the application of displacement ventilation in hospital environment is the lock-up effect of pollutants within the stratification layers. The exhaled air from a standing (Bjørn and Nelsen 2002) or lying occupant breathing sideways, along the stratification (Qian et al. 2006) will move further into the space, because

the temperature gradient decreases the turbulent mixing between the exhalation jet and its surroundings. However one of the major release mechanisms of pathogens from a sick person is via coughing due to its very high initial momentum. The spread of cough air in occupied spaces with displacement ventilation has not been studied yet.

The impact of ventilation rate and distance on exposure of a doctor and a second patient to coughed air from the sick occupant in a two-bed hospital room with displacement air distribution was studied. Some of the obtained results are presented in this paper.

METHODS

Experiments were designed and performed in a full-scale room with dimensions 4.65 m x 4.65 m x 2.60 m (W x L x H) furnished to simulate a hospital isolation room with two beds. The distance between the beds was set to 1.3 m. Five ceiling-mounted light fixtures (6 W each) provided the background lighting. The room was located in a tall hall, where the temperature was kept constant and equal to the air temperature in the test room. A heated dummy (60 W) with simplified body geometry, equipped with a coughing machine was used to simulate a coughing sick patient lying in one of the beds. The characteristics of the cough were: cough peak flow rate – 14 L/s ±1.7 L/s; maximum velocity – 52 m/s; total volume – 1.9 L ± 0.1 L; time span – 0.55 s. The mouth of the coughing patient was simulated by a circular opening (diameter of 0.021 m). A dressed breathing thermal manikin (1.02 Clo) with realistic human body size, shape and surface temperature distribution was used to resemble a “doctor”. This manikin consisted of 17 body segments. A second thermal manikin of 23 body segments was used to simulate a second patient lying in the other bed aligned with the bed of the coughing patient. The manikin was dressed with patient pyjama of 0.75 Clo. Each manikin released 60 W sensible heat load on average. Two electrical oil filled radiators 0.4 m x 1.12 m x 0.01 m (H x L x W) were used during the experiments to mimic hospital equipment and increase the heat load in the room. Their total power was 800 W. The radiators were with on off control based on the temperature of the oil. The layout of the set-up is shown in Figure 1.

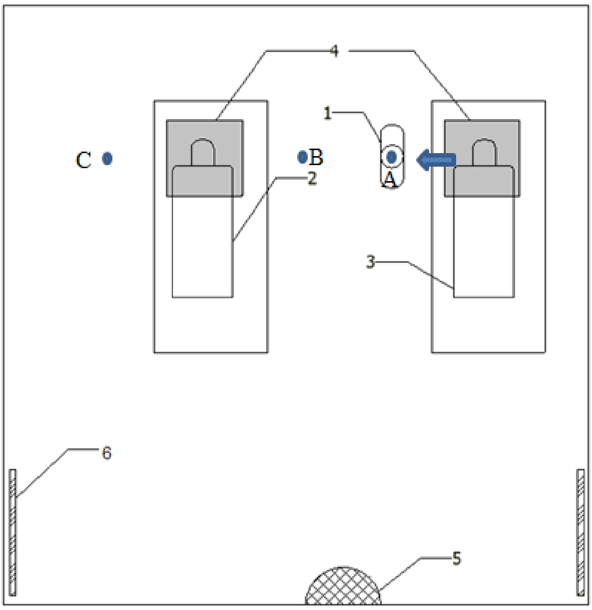


Figure 1. Experimental set up, top view of test room: 1 – doctor; 2 – exposed patient; 3 -”sick” patient; 4 - exhaust diffusers; 5 - supply diffuser; 6 – radiators.

During all experiments displacement mechanical ventilation system was used. The supply air was 100% outdoor air with no recirculation. The supply diffuser was a semicircular perforated unit for wall installation. A semi-circular supply air diffusion pattern was chosen. Two rectangular perforated ceiling mounted diffusers were used for exhausting the air from the room. They were located above the heads of the patients (position 4 on Figure 1). The exhausted air was equally balanced between the two diffusers.

Experiments were performed at two air-change rates: 3 and 6 h^{-1}. Room temperature was kept at 22˚C (at 1.1 m height), while the relative humidity was not controlled but was measured to be between 30% and 40% during all experiments. The supply temperature was kept at 17 ˚C. According to the data from the manufacturer the near zone of the displacement supply diffusors (i.e. the zone where the supply velocity drops to 0.2 m/s) for the two studied levels of ventilation was either 1.1 m (3 ACH) or 1.6 m (6 ACH).The coughing patient was lying on one side and was facing the doctor (Figure 1). Measurements were performed when the doctor was positioned downstream from the coughing patient at 0.55, 1.1 and 2.8 m (points A, B and C in Figure 1). The coughed flow was 100% CO_2. The time dependent CO_2 concentration was measured at the mouth of the doctor with a specially developed instrument (PS331) with time constant of 0.8 s and a sampling rate of 4 Hz. The sampling tube of the PS331 was placed at the mouth 0.005 m away from the lips and the breathing function of the heated manikin was switched off. As reported in the literature the CO_2 concentration measured in this way is equal to the CO_2 concentration in the air inhaled by breathing thermal manikin (Melikov and Kaczmarczyk 2007). The acquired data were analysed by specially developed software. The software used second order polynomial extrapolation to get the initial value of the CO_2 concentration up to 14 000 ppm by applying calibration equations. Frequency correction of the signal from the instrument and compensation for the time needed for the CO_2 sample to travel from the measuring location to the instrument was applied. For each of the studied 6 conditions (two ventilation rates and three distances between the coughing patient and the doctor) 15 to 20 "coughs" were performed and averaged. Only one cough at a time was generated. Every coughs was initiated after the background CO_2 level reached the background level before the cough, which depended on the level of the background ventilation.

In order to avoid transport of tracer gas (CO_2) in the surrounding hall the experimental chamber was kept at a slight under pressure of -1.6±0.2 Pa during all measurements. Temperature and flow rate of supply and exhaust air as well as temperature inside the test room were recorded and controlled constantly and separately from the control of the surrounding hall.

The excess concentration of CO_2 over the background level was used as the evaluation criteria for exposure assessment. Two more parameters were analyzed, namely the Peak Concentration Level (PCL) and the Peak Concentration Time (PCT). PCL is defined as the maximum concentration measured at the mouth of the doctor after a cough is generated; PCT is defined as the time at which the PCL is reached after a cough is generated.

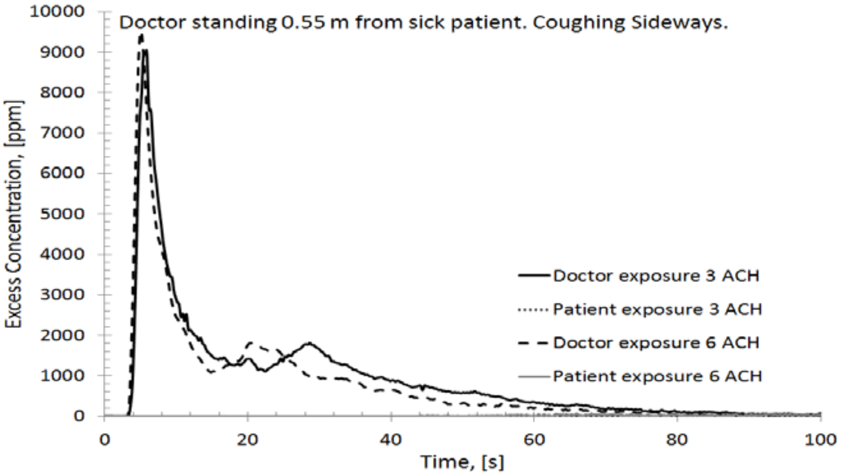
RESULTS AND DISCUSSION

The excess CO_2 concentration levels measured at the mouths of the exposed patient and the doctor when the total volume ventilation was running at 3 and 6 ACH are shown in Figure 2a. In this case the sick patient is lying sideways and facing the doctor. As expected the concentration is quite high at the mouth of the doctor at both air change rates since the doctor was standing close to the source patient. The Peak Concentration Level (PCL) at 6 ACH is slightly higher than that registered at 3 ACH but still the values are quite close, i.e. 9050 and 9510 ppm respectively. The time when the PCL is reached (Peak Concentration Time: PCT) is 5.8 and 5.1 s respectively for 3 and 6 ACH. The double increase in supply flow rate kept total exposure time the same (around 80 sec, Figure 2a) but resulted in steeper decay at 3 ACH compared to 6 ACH. The secondary concentration peak, observed 30 s for 3 ACH and 20 s for 6 ACH after the cough, can be due to entrainment of re-bounced from floor coughed air by the restored boundary layer around the doctor's body. The measured temperature (not shown) at 6 ACH was lower than that at 3 ACH up to approx. 1.1 m height (1.5 K lower at height of 0.05 m). Thus the free convection layer around manikin's body had higher velocity at 6 ACH than at 3 ACH (due to the greater difference in manikin's surface temperature and surrounding air temperature). Similar secondary peak have been reported from Bolashikov et al. (2010) with mixing overhead background ventilation. The CO_2 concentration level at the mouth of the exposed patient was very close to the background level and unaffected by the ventilation rate. The body of the doctor fully deflected the incoming cough and "shielded" the second patient from further exposure.

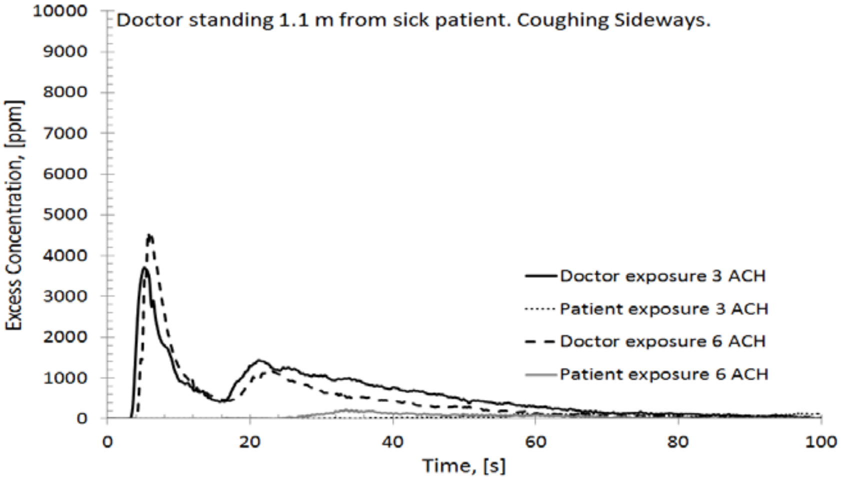
Figure 2b shows the CO_2 excess concentration measured at the mouths of the doctor and the second patient, when the former was standing 1.1 m from the sick patient. In this condition similar to the case when the doctor stood 0.55 m away, the higher ventilation rate (6 ACH) resulted in elevated exposure. The PCL was 3706 ppm for 3 ACH and 4580 ppm for 6 ACH. The PCT at 6 ACH was shorter than the one obtained at 3 ACH. Nevertheless it is shown that at both air change rates the concentration levels remain high. At 6 ACH the stratification occurred above the level of the coughed jet (approx. 0.9 m). At 6 ACH most of the coughed air, although with relatively high velocity, remained below the stratification height while at 3 ACH the cough was discharged above it. The measurements (not reported here) revealed that the vertical concentration distribution within the room was different. Similar to the case when the doctor was 0.55 m away from the sick patient a secondary concentration peak is observed. It also appears slightly faster at 3 ACH compared to 6 ACH. At 6 ACH there is also an increase in the excess CO_2 concentration measured at the mouth of the second patient. In this case the back of the doctor was around 0.1 m from the rim of the bed of the second patient. The convection flow around the doctor's body transported pollutants into the breathing zone of the exposed occupant. Clearly the displacement ventilation does not provide sufficient protection from coughed air generated by a sick occupant even at 1.1 m away from the source.

The results measured at 3 and 6 ACH when the doctor is standing 2.8 m from the source patient are shown in Figure 2c. The excess concentration at the mouth of the doctor and the mouth of the second patient increased when the air supply flow rate was increased: PCL was 912 ppm and 1500 ppm for the doctor and 5453 ppm and 6511 ppm for the second patient at 3 and 6 ACH respectively. The exposure to coughed air was higher for the exposed patient than for the doctor since the doctor was standing 2.8 m downstream the cough trajectory (point C, Figure 1), i.e. behind the bed of the second patient. Several seconds after the initial peak was registered at the mouth of the exposed patient a high peak is observed at the mouth of the doctor. The cough air although partly deflected by the body of the second patient remained mostly below the stratification height at 6 ACH while at 3 ACH it was more above it resulting in increased mixing. Much lower exposure for the doctor standing at 2.8 m downstream from the coughing sick patient are reported with mixing air distribution at 3 and 6 ACH by Bolashikov et al. (2010) due to lack of stratification.

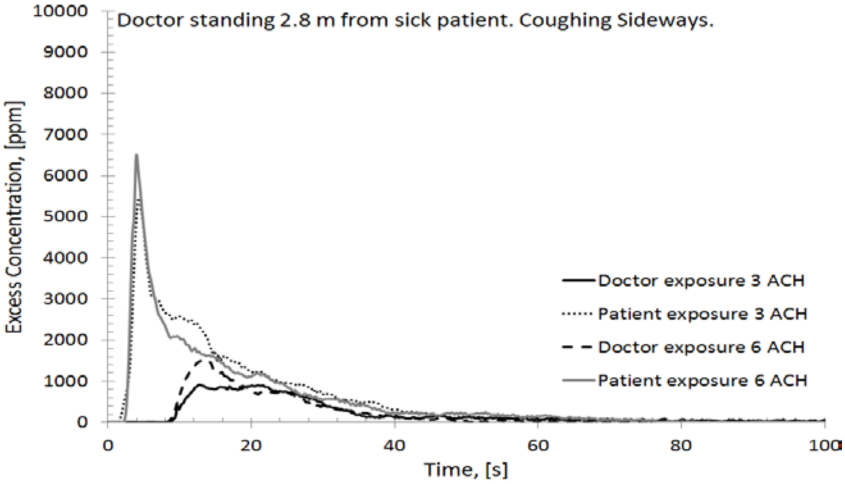
The results of the present and previous studies (Qian et al. 2006, Bolashikov et al. 2010) show that total volume air distribution patterns, displacement and mixing, are not effective in decreasing the risk of airborne cross infection. In rooms with mixing air distribution increase of the ventilation rate will decrease the risk of airborne cross infection but will increase the risk of draught discomfort due to high room air velocity and the energy consumption.



a)



b)



c)

Figure 2. Excess concentration of CO2 at the mouths of the doctor and the second exposed patient when the sick patient coughs sideways facing the doctor at 3 and 6 ACH. The doctor is standing a) 0.55 m, b) 1.1 m and c) 2.8 m downstream the cough along the center line starting from the mouth of the sick occupant.

Source control by advanced air distribution methods enabling for removal of the contaminated respiration air close to the source need to be developed and implemented. Melikov et al.

(2011) reported on bed integrated ventilation based on the “push and pull” air distribution principle which removes most of the contaminated exhaled air locally at the bed of the sick patient before mixing with room air. This leads to decreased exposure risk and may save energy due to decreased background ventilation rates.

CONCLUSIONS

- In a simulated two-bed hospital patient room ventilated by displacement air distribution pattern and with one of the patients infected and coughing sideways, the exposure of the doctor to coughed air at 6 ACH was higher compared to that at 3 ACH regardless of the distance from the sick patient. The exposure of the second patient was also high when not protected by the doctor standing between the two beds as an obstacle for the coughed flow; The results reveal that stratification height was important factor for the studied exposure;
- In hospital patient room displacement ventilation can’t provide reliable protection against airborne cross-infection to pathogen released via cough in ambient air. Development of advanced air distribution methods and source control for removal and disinfection of pathogen contaminated air before it is mixed with the room air is recommended.

ACKNOWLEDGEMENT

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REFERENCES

Bjørn E. and Nielsen P.V., 2002, Dispersal of exhaled air and personal exposure in displacement ventilated rooms, Indoor Air, pp.147-pp.164;

Bolashikov Z.D., Kierat, W., Melikov A.K., Popiołek, Z., 2010, Exposure of health care workers to coughed airborne pathogens in a hospital room with overhead mixing ventilation: impact of the ventilation rate and the distance downstream from the coughing patient, IAQ 2010: Airborne Infection Control – Ventilation, IAQ & Energy, Paper ID: TOPC-00126-2010;

Lai A.C.K and Cheng Y.C., 2007, Study of expiratory droplet dispersion and transport using a new Eulerian modeling approach, Atmospheric Environment 41 (35), 7473-7484.

Melikov. A.K. and Kaczmarczyk. J.,2007, Indoor air quality assessment by a breathing thermal manikin, Indoor Air 17 (1). pp.50-59;

Melikov A.K., Bolashikov Z.D. and Georgiev E., 2011, Novel ventilation strategy for reducing the risk of airborne cross infection in hospital rooms, Indoor Air 2011, Texas USA, Paper ID: 1037;

Mundt E., 2008, Air quality in the near zone of humans with different ventilation strategies, Proceedings of the 29th AIVC Conference;

Qian H., Li Y., Nielsen P.V., Hyldgaard C.E., Wong T.W., Chwang A.T.Y., 2006, Dispersion of exhaled droplet nuclei in a two-bed hospital ward with three different ventilation systems. Indoor Air, 16, pp.111–pp.128;